I² R Innovative Imaging & Research

Advanced LED Illuminated Calibration Sphere

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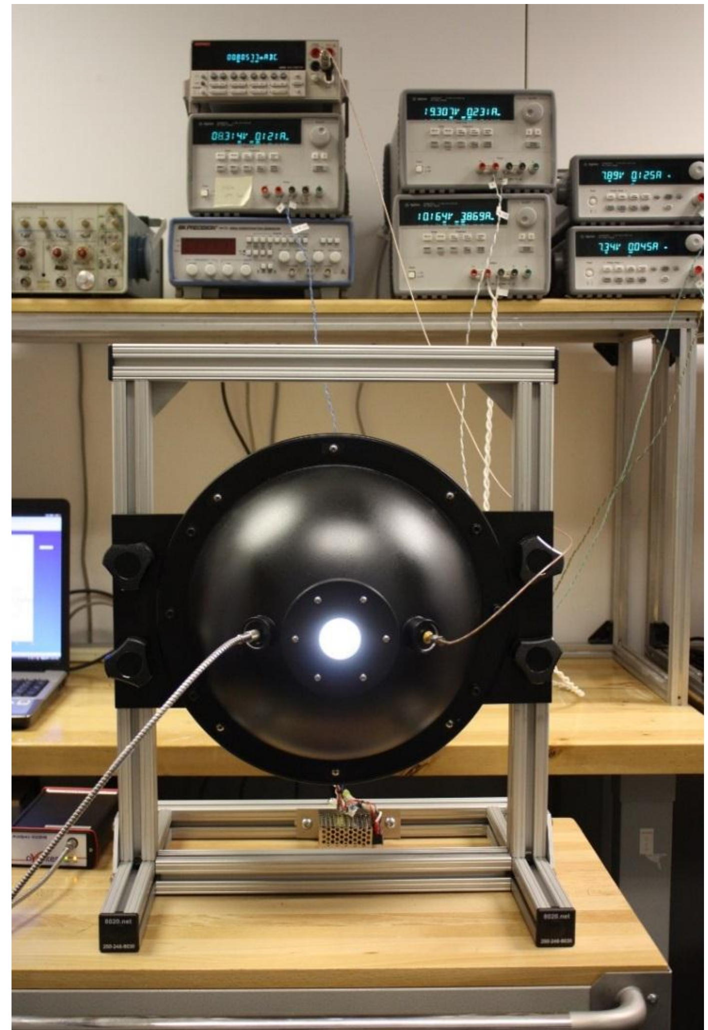
Radiometric Calibration Integrating Spheres

- Spherical shell with internal illumination
- Used to perform relative and absolute radiometric calibration on remote sensing imaging systems (Vis-SWIR) and spectroradiometers

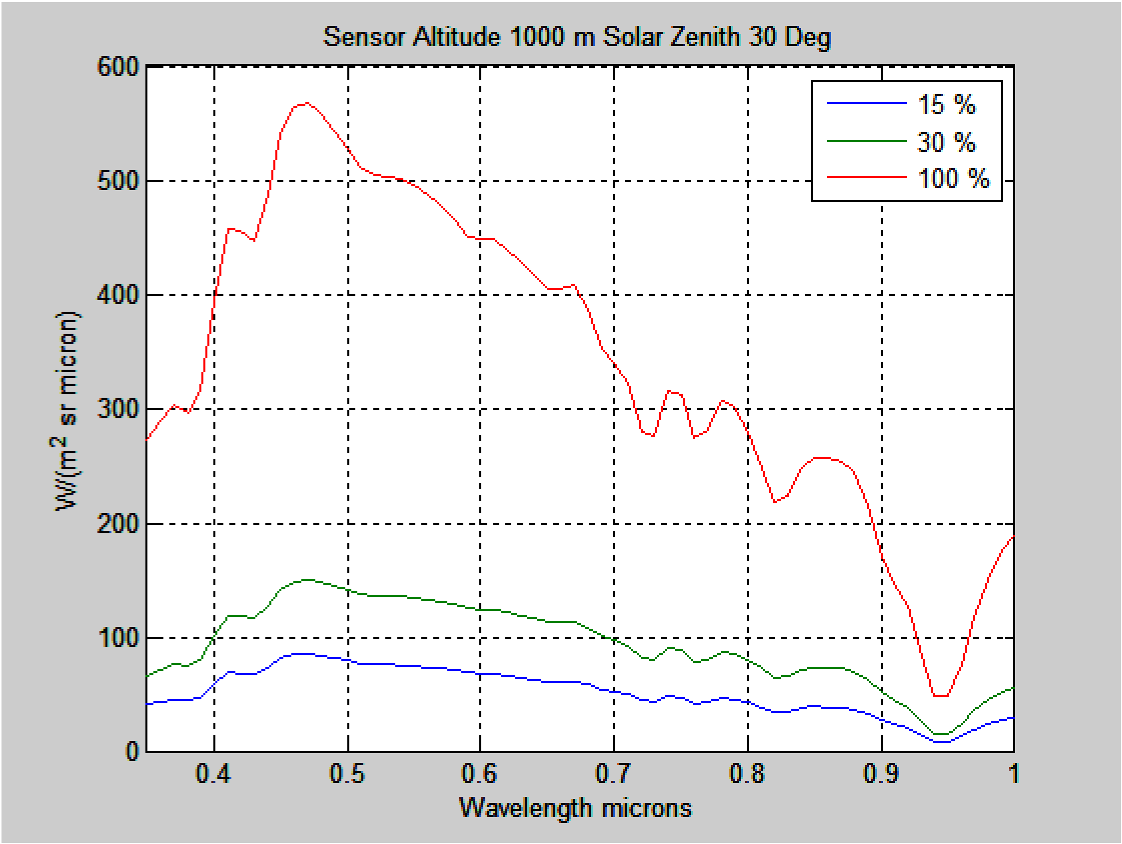


General Sphere Requirements/Goals Traditional Aerial Cameras (VNIR)

Requirement	Goal	Reason
Spectral Range	350–1100 nm	Solar reflective region
Spectral Shape	Approximately solar	Solar spectrum minimizes calibration error
Max Radiance Level (visible)	~ 100–200 W/(m^2 sr μm)	Typical bright scene
Radiometric Adjustment Level	3 decades to <1% of max	Linearity and dynamic range test
Absolute Radiometric Calibration Accuracy	NIST traceable to 5% or better	LDCM specification
Relative Radiometric Accuracy (Pixel-to-Pixel)	<1%	LDCM specification
Spatial Uniformity (before angular averaging)	<2% across aperture and FOV	Relative radiometry
Small Area Spatial Uniformity	<0.1% (small area variation)	SNR>200 are common
Short Term Temporal Stability	<0.1% drift over ~1 second	SNR>200 are common
Exit Port Diameter	~400 mm	
Calibration Interval	1 Year	Yearly is common

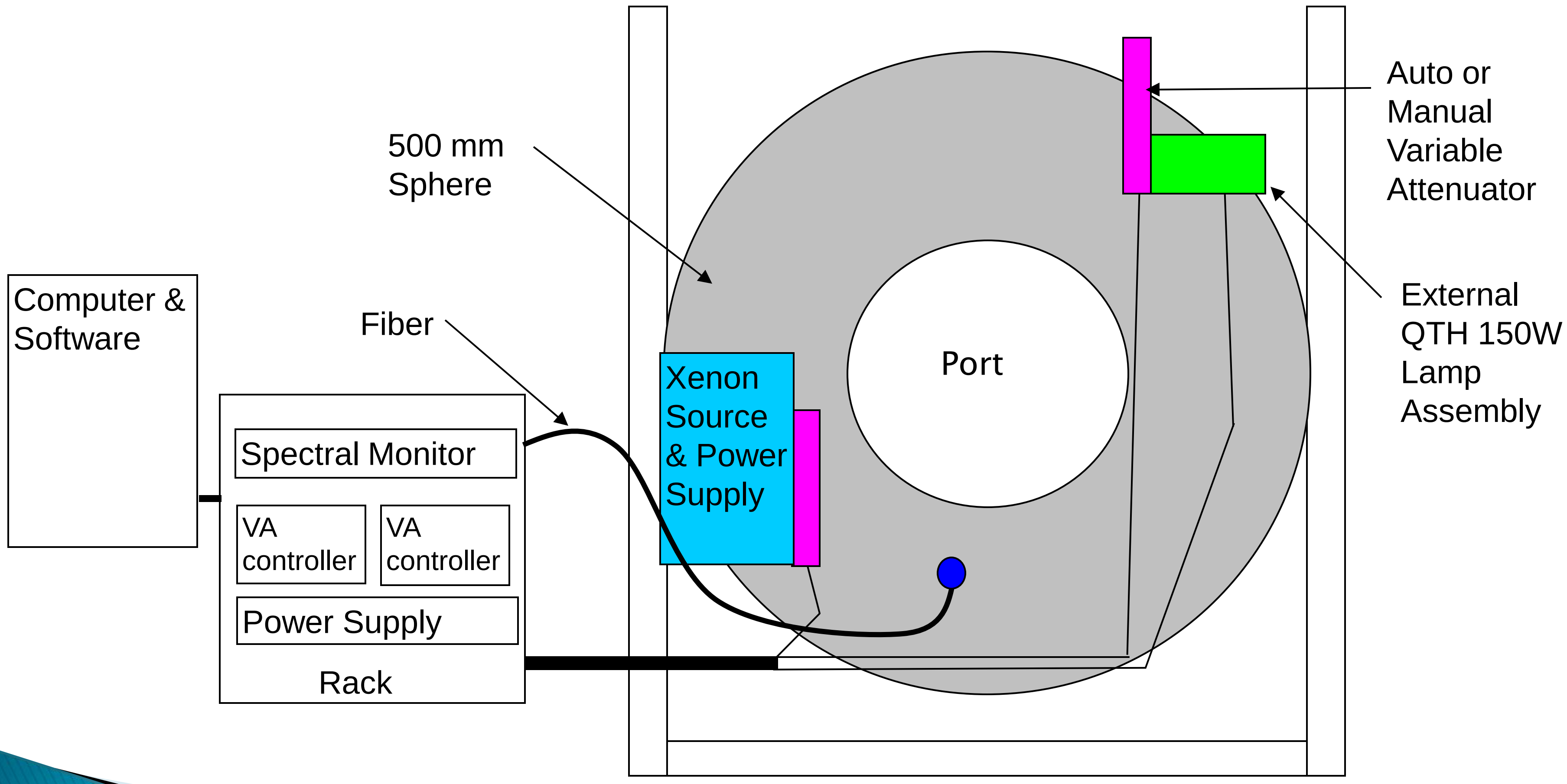
Spectral Radiance Requirements

At Sensor Radiance 1000 m Altitude
for 15%, 30% and 100% reflectance at MLS 23 km Vis

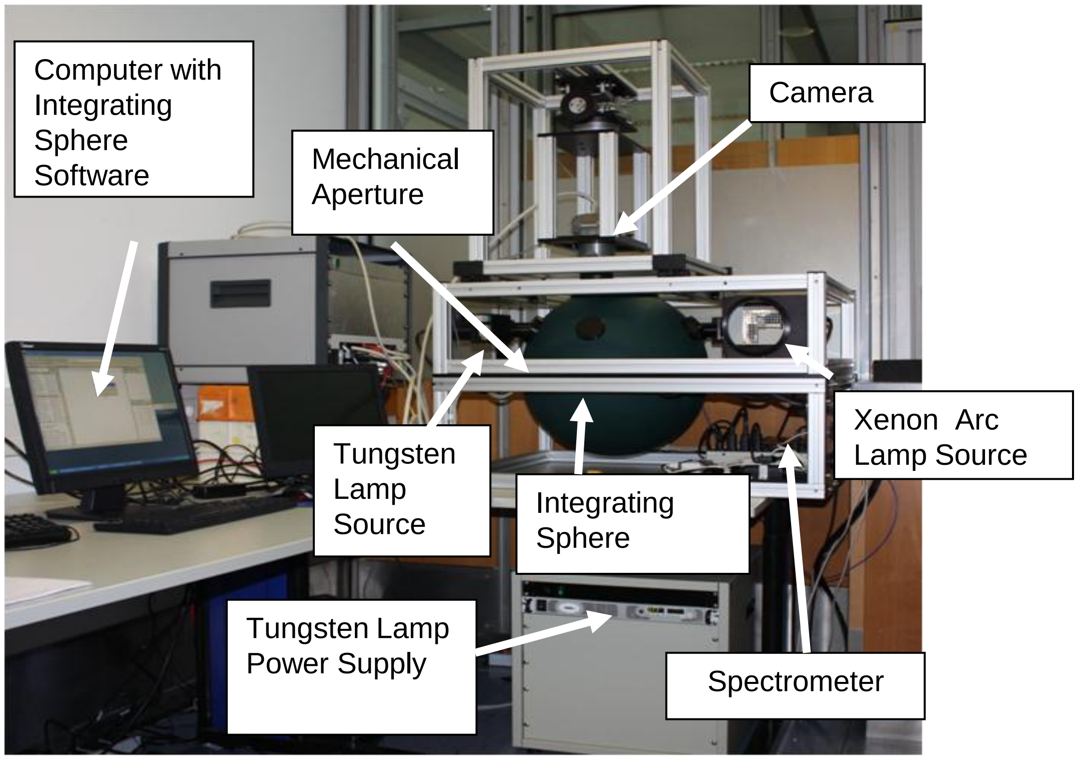


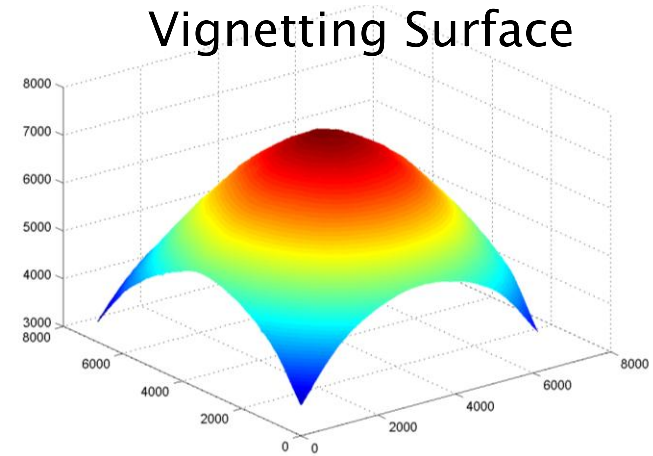
Goal radiance in sphere ~100-200 Watts/(m^2 sr micron)

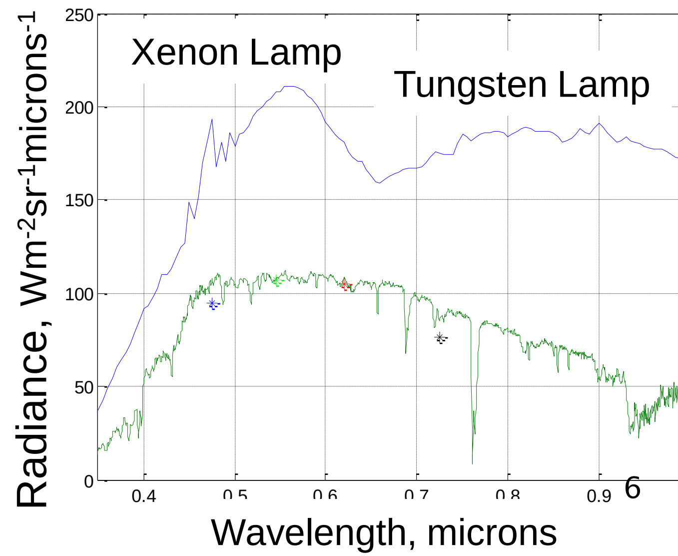
Traditional Integrating Sphere



Traditional Integrating Sphere Example



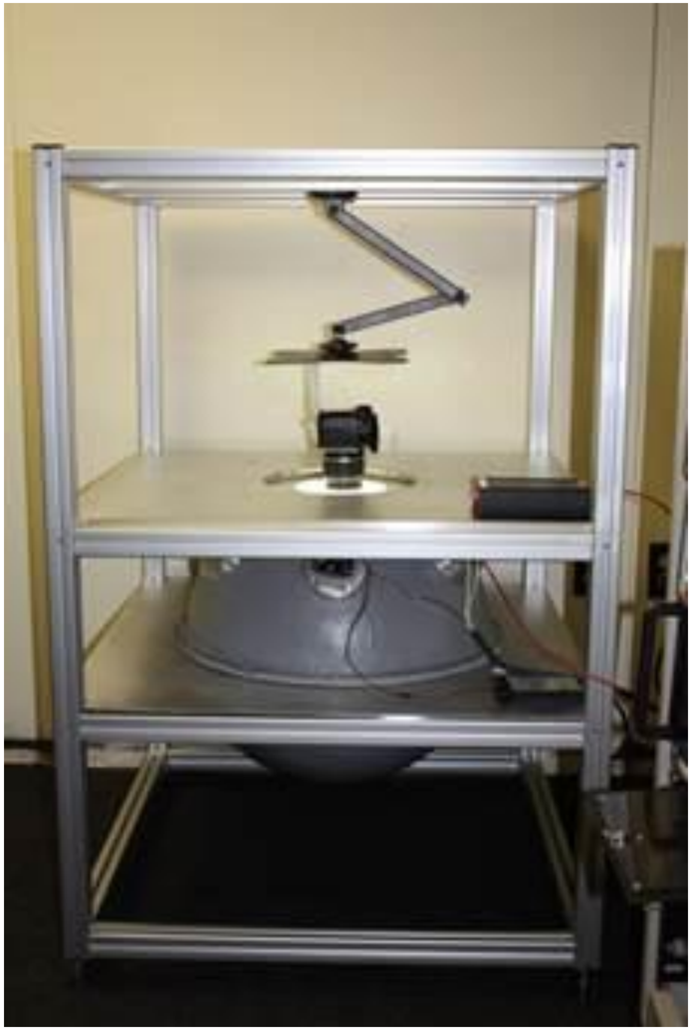


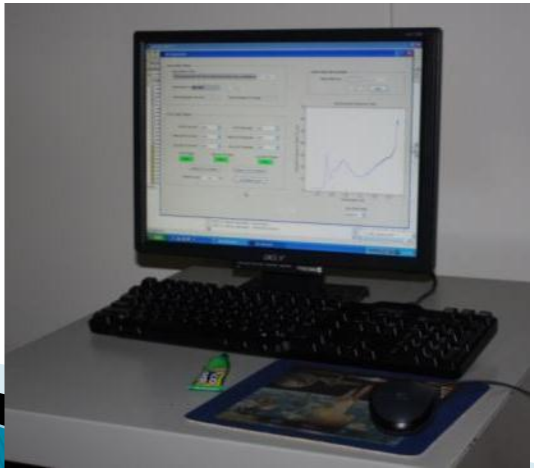


- Traditional spheres use quartz tungsten lamps and/or arc lamps
- Mechanical apertures needed to vary radiance or lamp changing

LED Illuminated Integrating Spheres

- High power LEDs
  - Enable the creation of simple electronically adjustable illumination
  - Enable large spheres to be constructed
- Computer controlled 0.5 m prototype shown on right





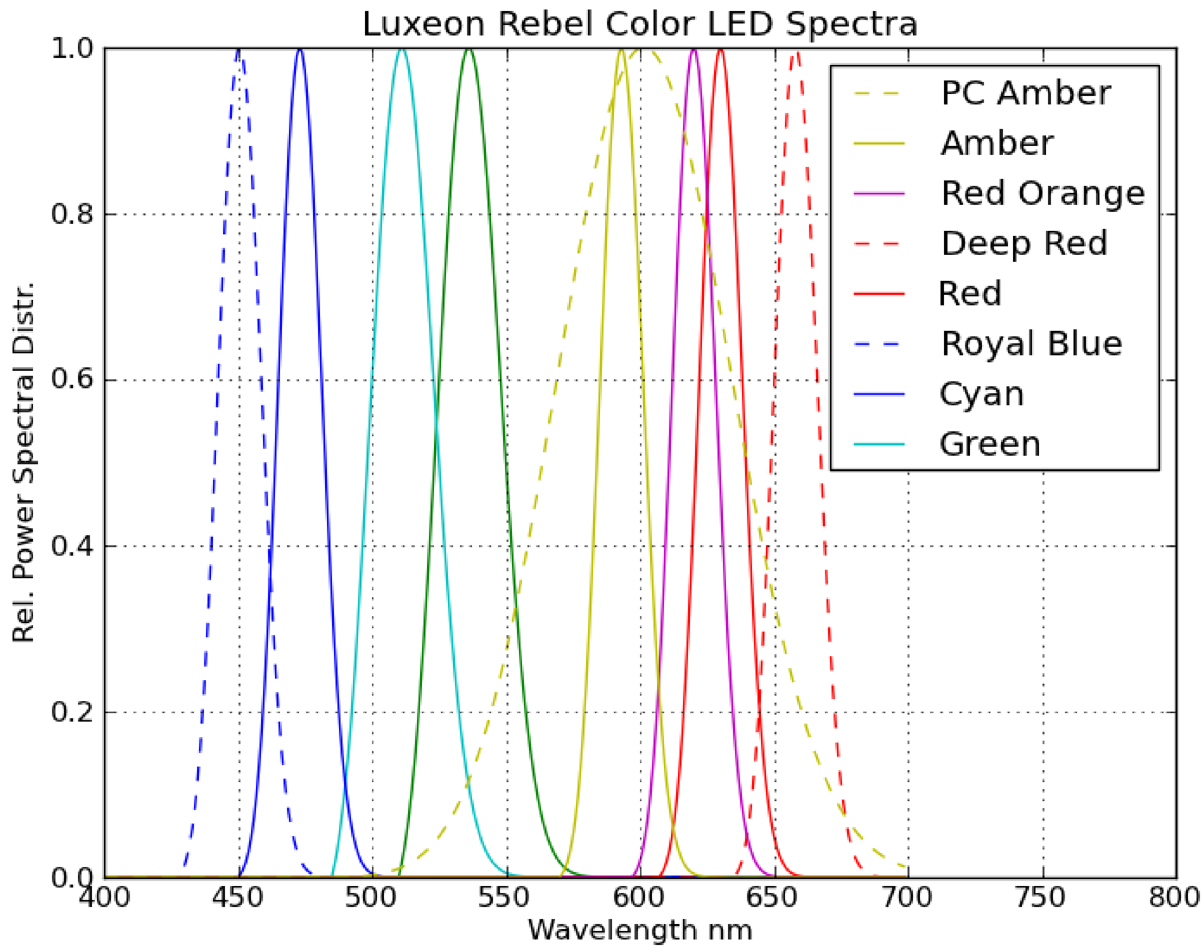
Why LEDs?

- Stable long life light sources
  - Operate >50,000 hours if properly operated
- Electronically adjustable
  - Eliminates or minimizes need for mechanically based light adjustment
- High efficiency enables large spheres to be illuminated
  - Wall plug efficiencies for single color devices can exceed 50%
- Spectrally smoother and less noisy than plasma sources (i.e. Xenon Arc)

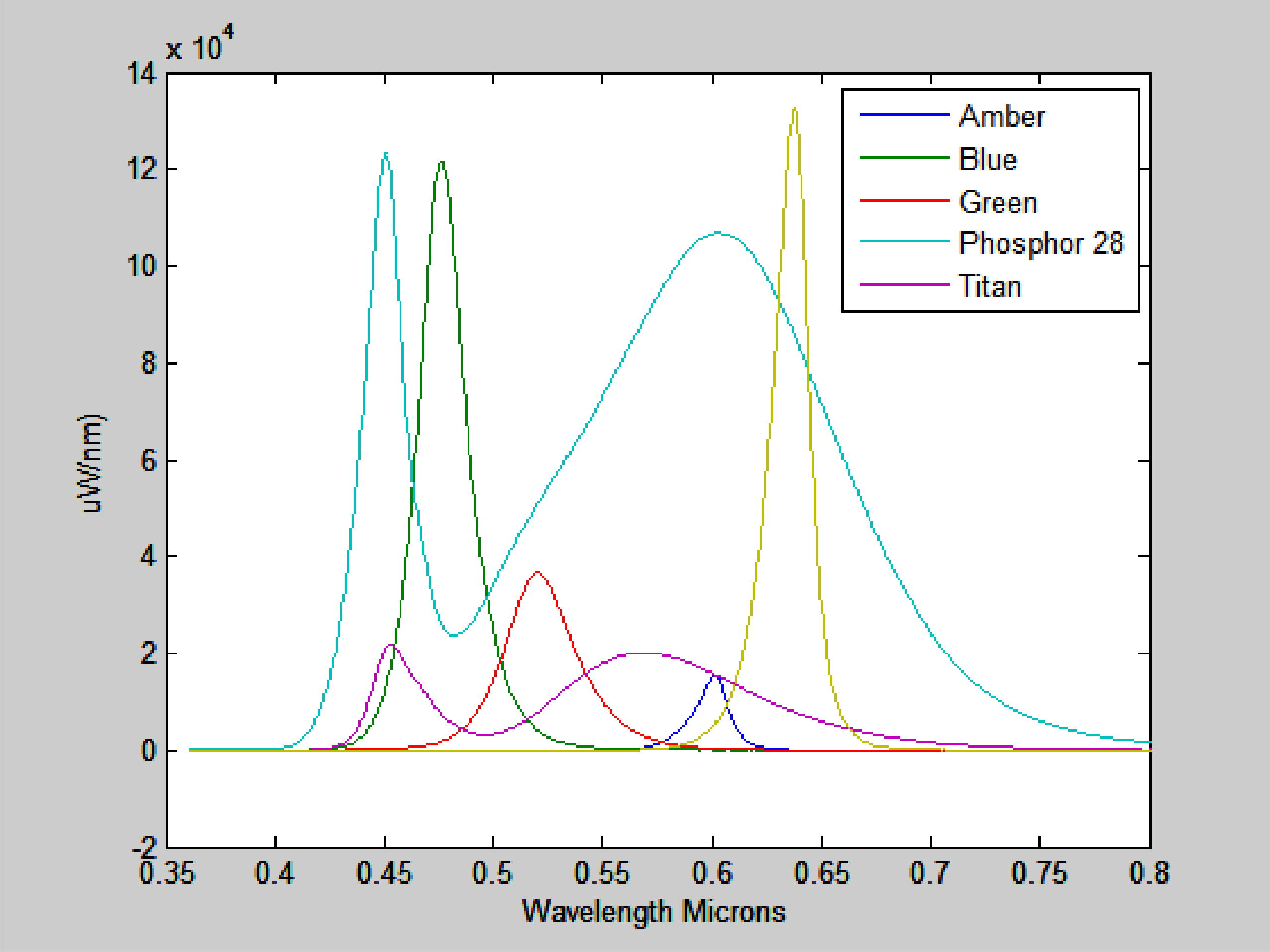
Why not LEDs?

- Designs require many LEDs to continuously cover a large spectral region without the use of phosphors
- Each separate LED type (color) may require its own controller (power supply)
- For some applications it is preferable to mix LEDs with continuum sources such as Quartz Tungsten Halogen (QTH) lamps to provide continuum
  - QTH lamps are more difficult to dim

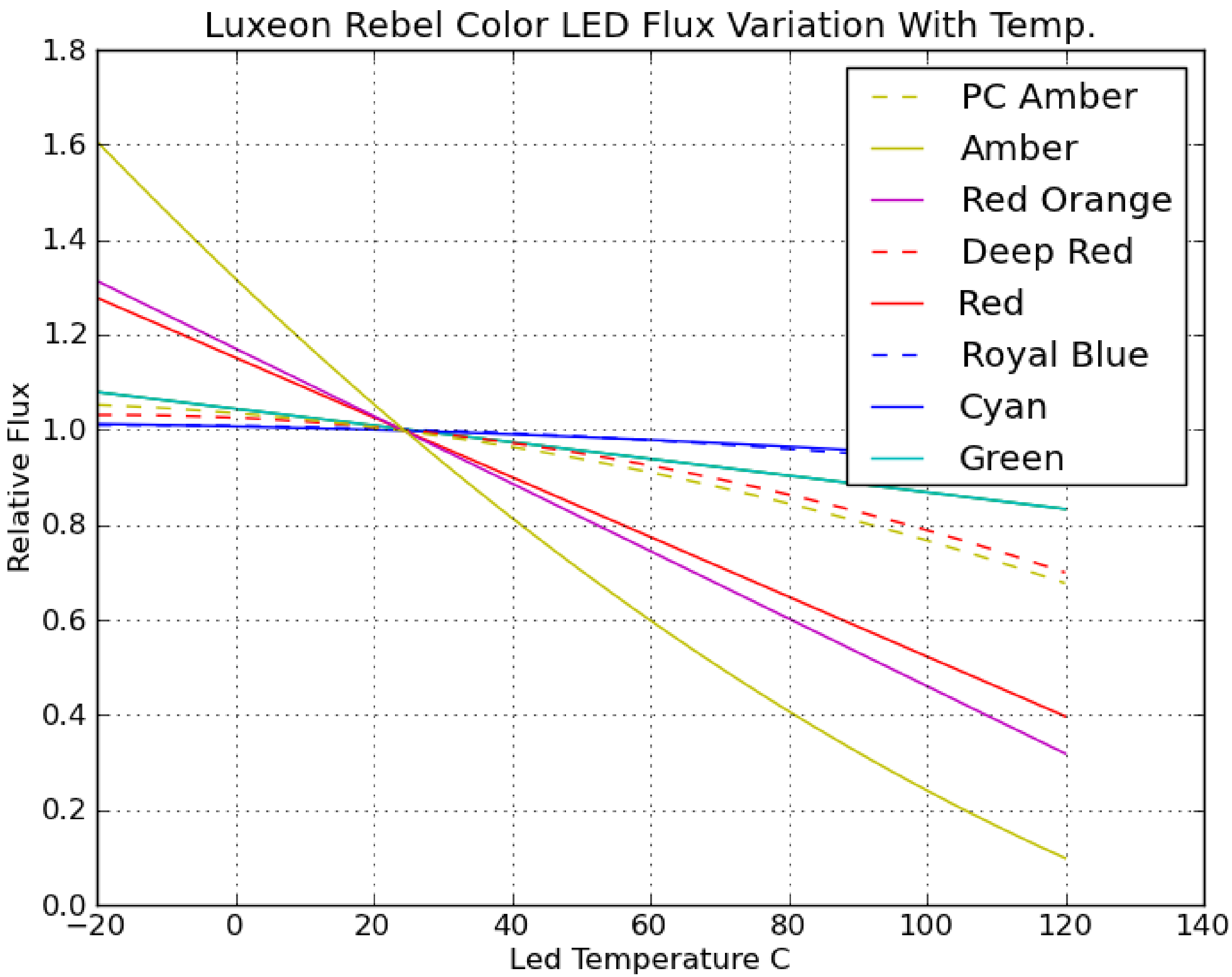
Visible LED Color Spectra



White Light and Color LED Spectra

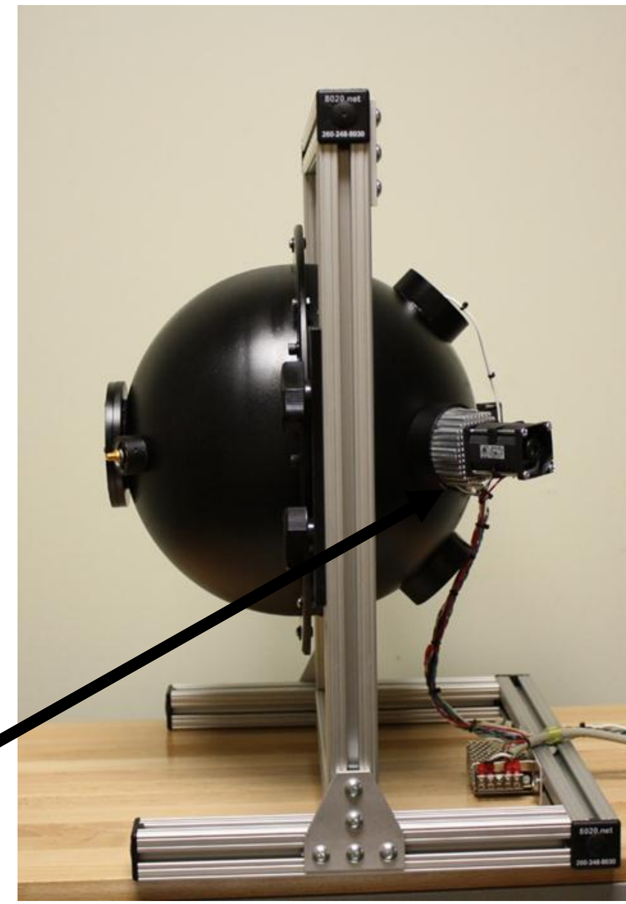


LED Flux Variation With Temperature

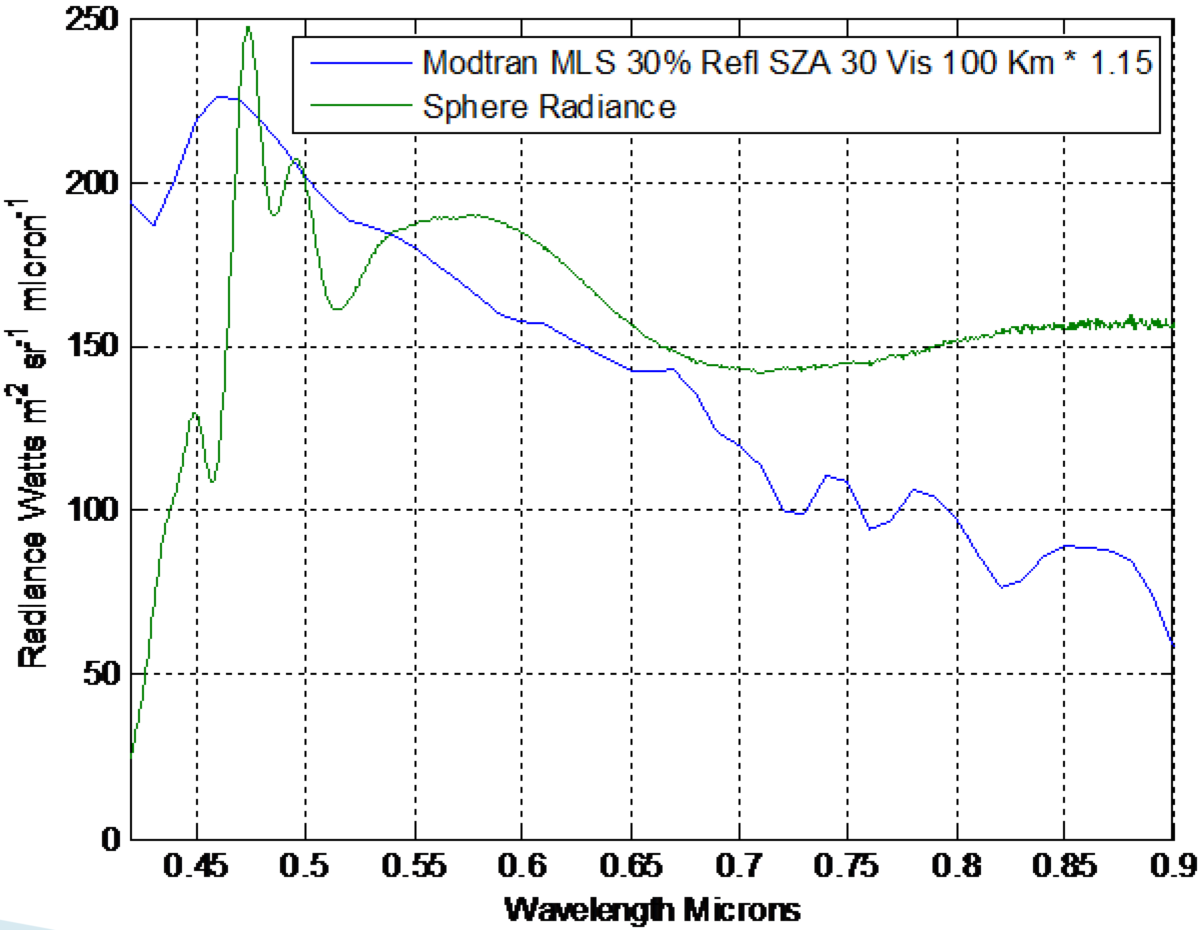


LED Sources & Mounting

LED Heat Sink



Spectral Synthesis With LEDs and QTH Lamps



Large Spheres

Need for Large Spheres

- Large aperture systems require large spheres >1 m in diameter
- Right photo shows a DMC I aerial camera being calibrated with a 1 m diameter integration sphere with a 300 mm exit aperture

Integrating Sphere Physics/Scaling

$$L_{Sphere} = \frac{\varphi}{\pi A_{Sphere}} * \frac{\rho}{1-\rho(1-f)}$$

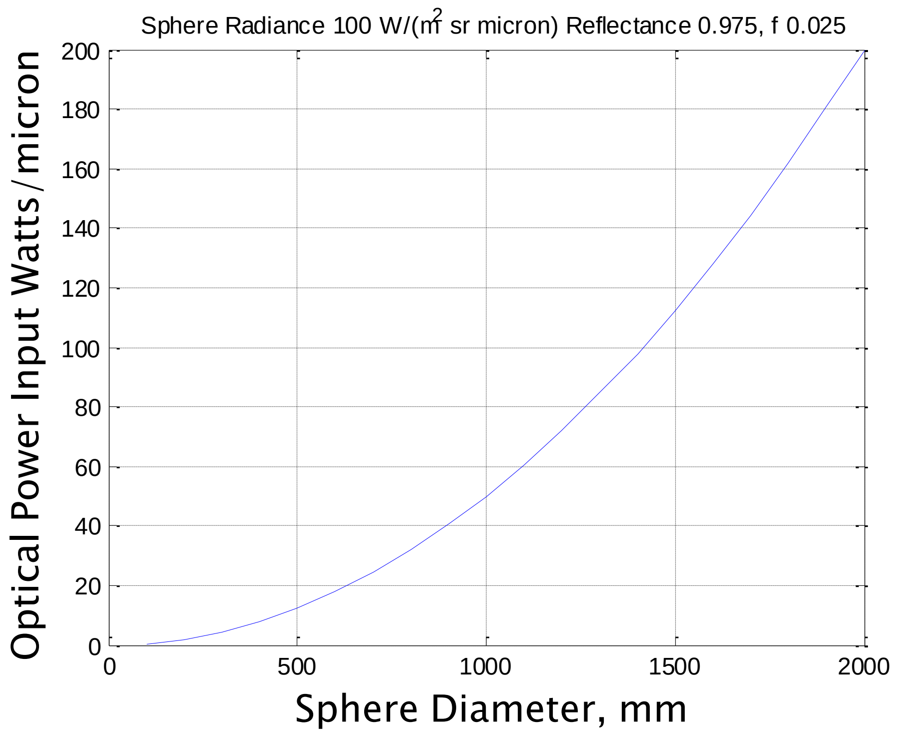
Where:

L_{Sphere} = Sphere Radiance [Watts/m² sr μm]

φ = Optical power input [Watts/ μm]

ρ = Sphere inner wall reflectance [ ]

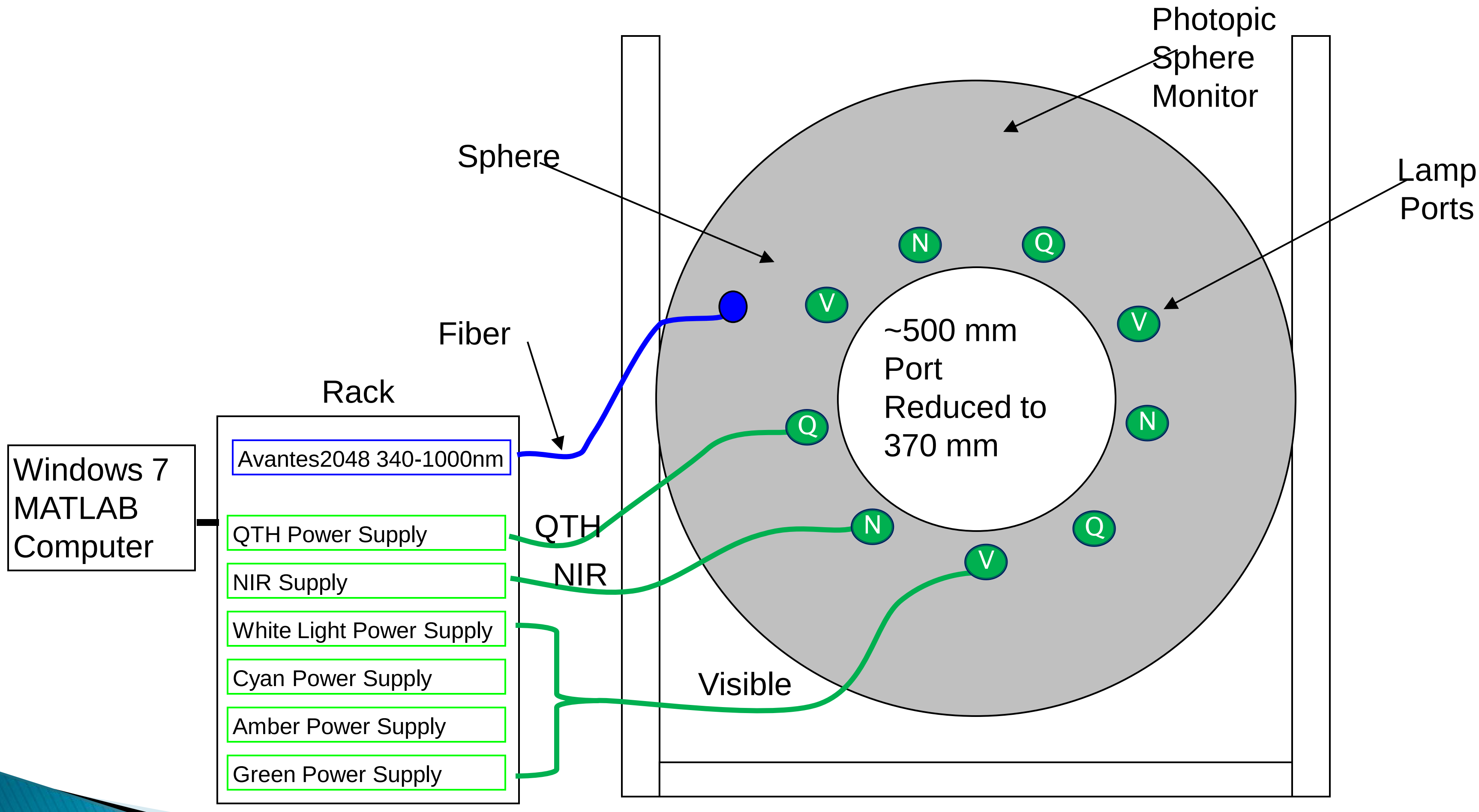
A_{Sphere} = Sphere area [m²]



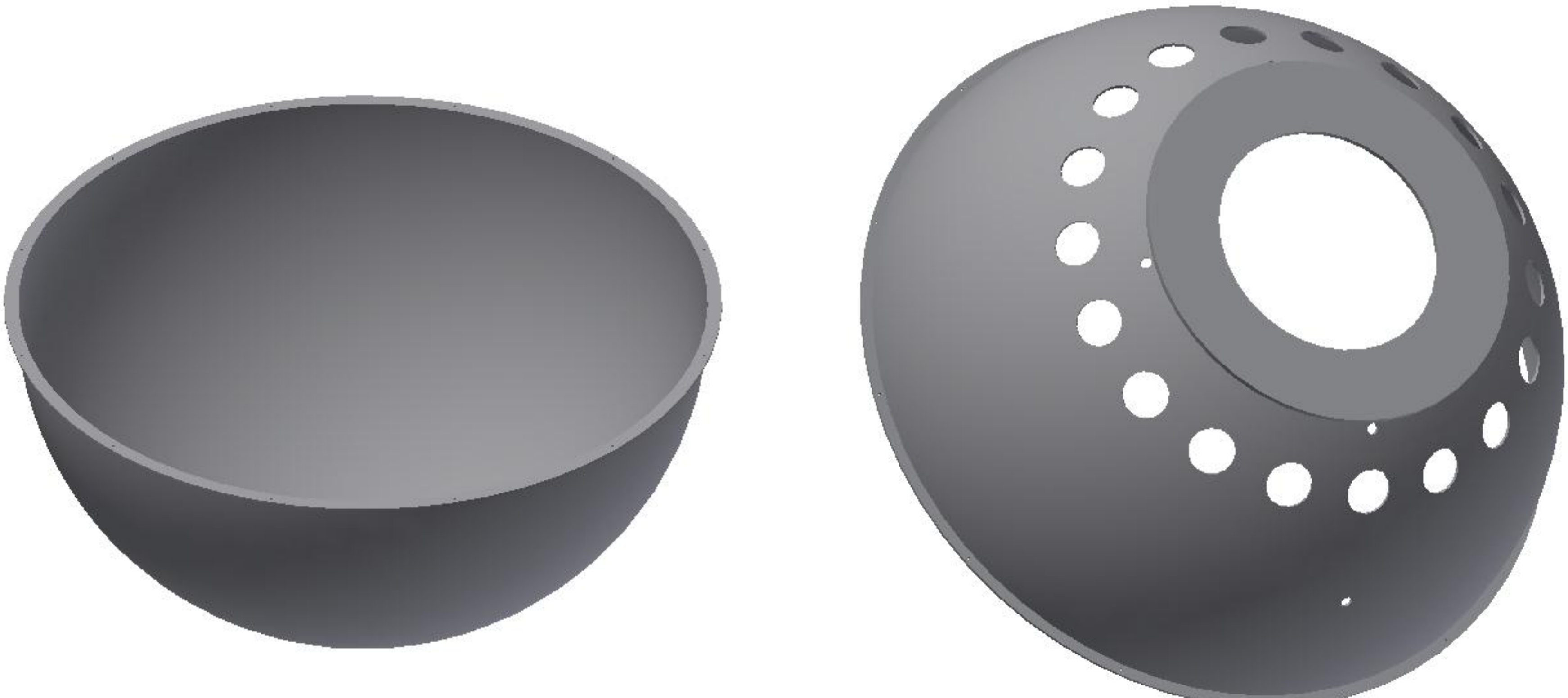
Sphere illumination input power scales with the square of the diameter

Efficiency of light source critical for scaling

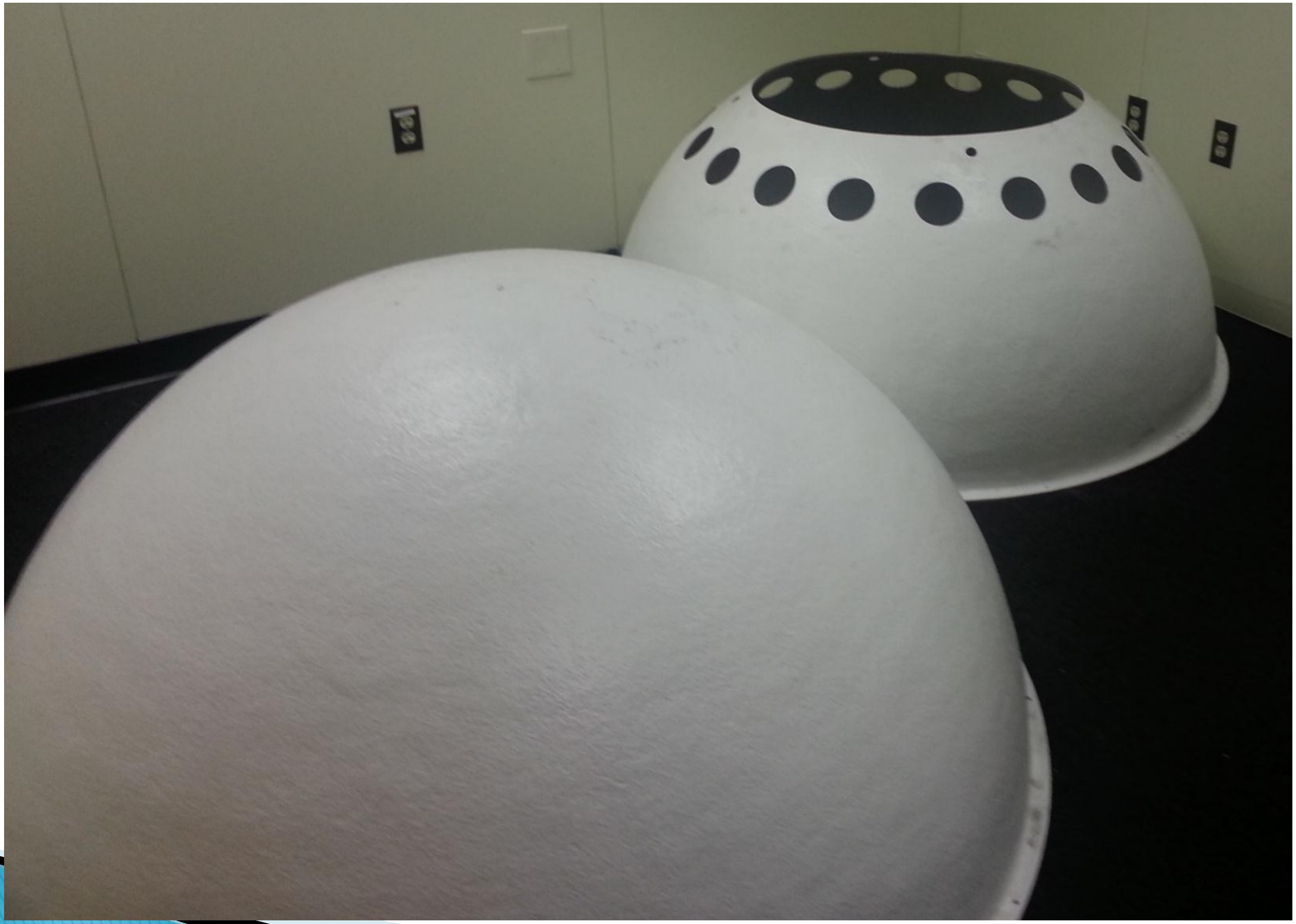
1500 mm Diameter Integrating Sphere Design



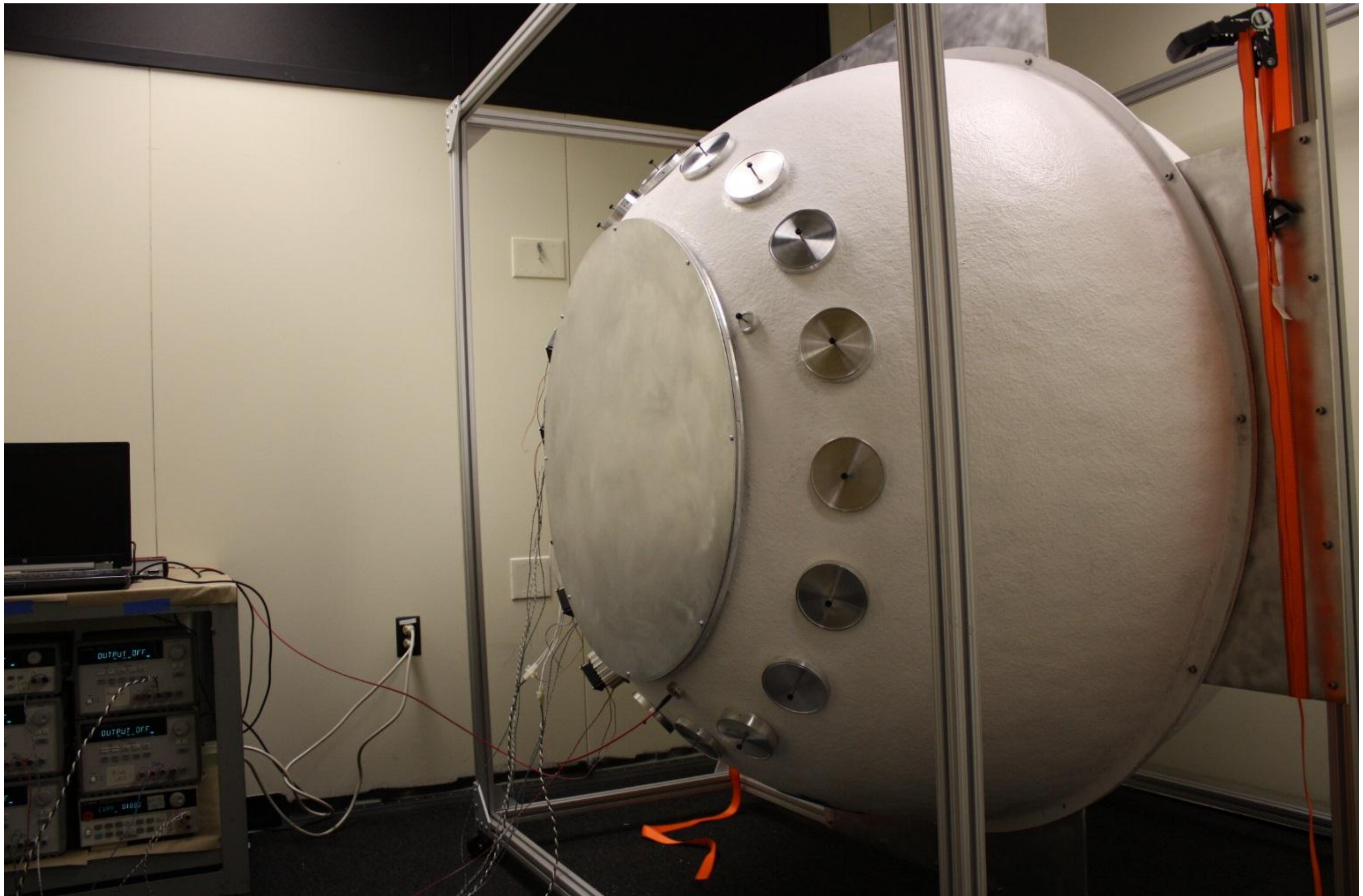
Hemispheres



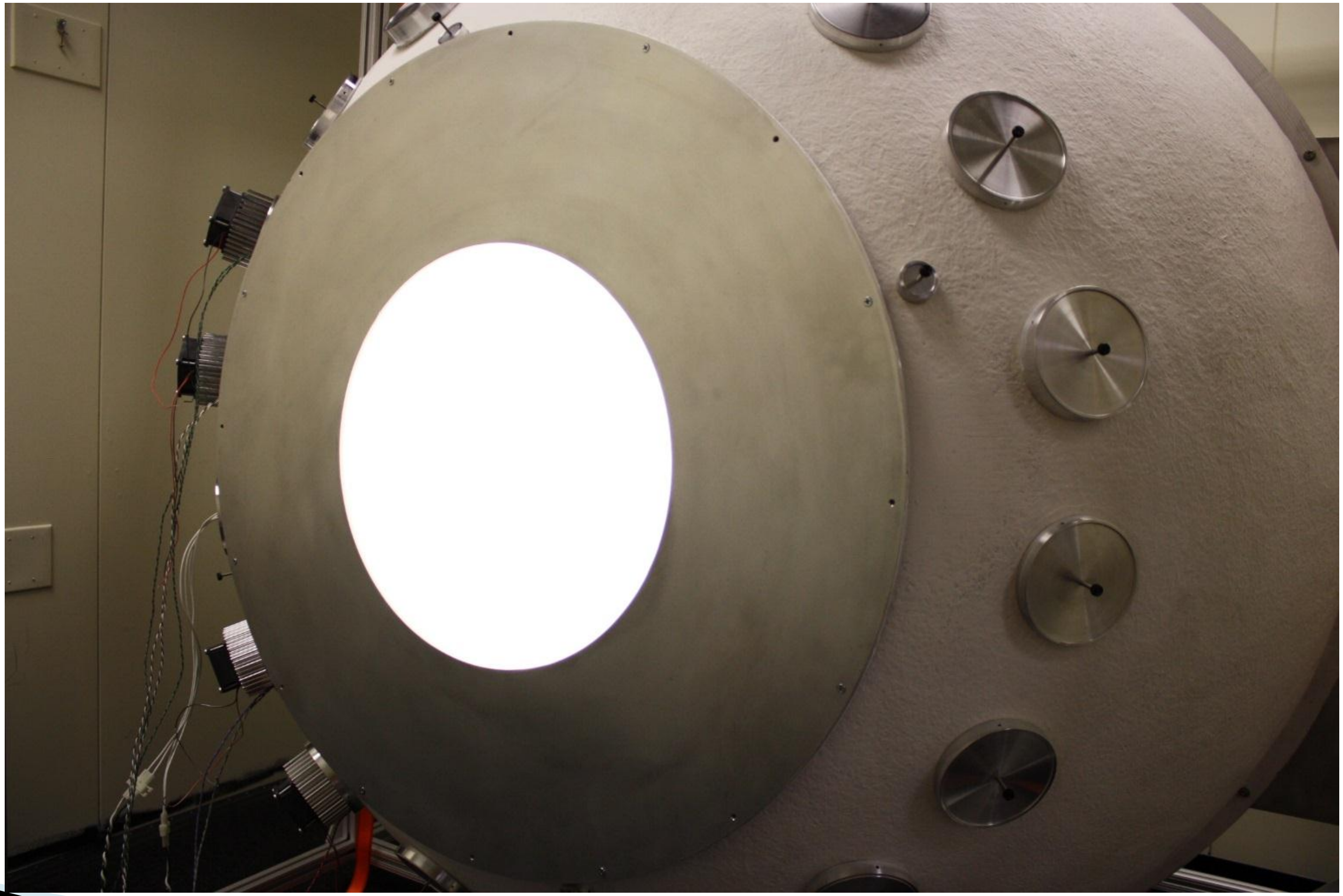
1500 mm Hemispheres



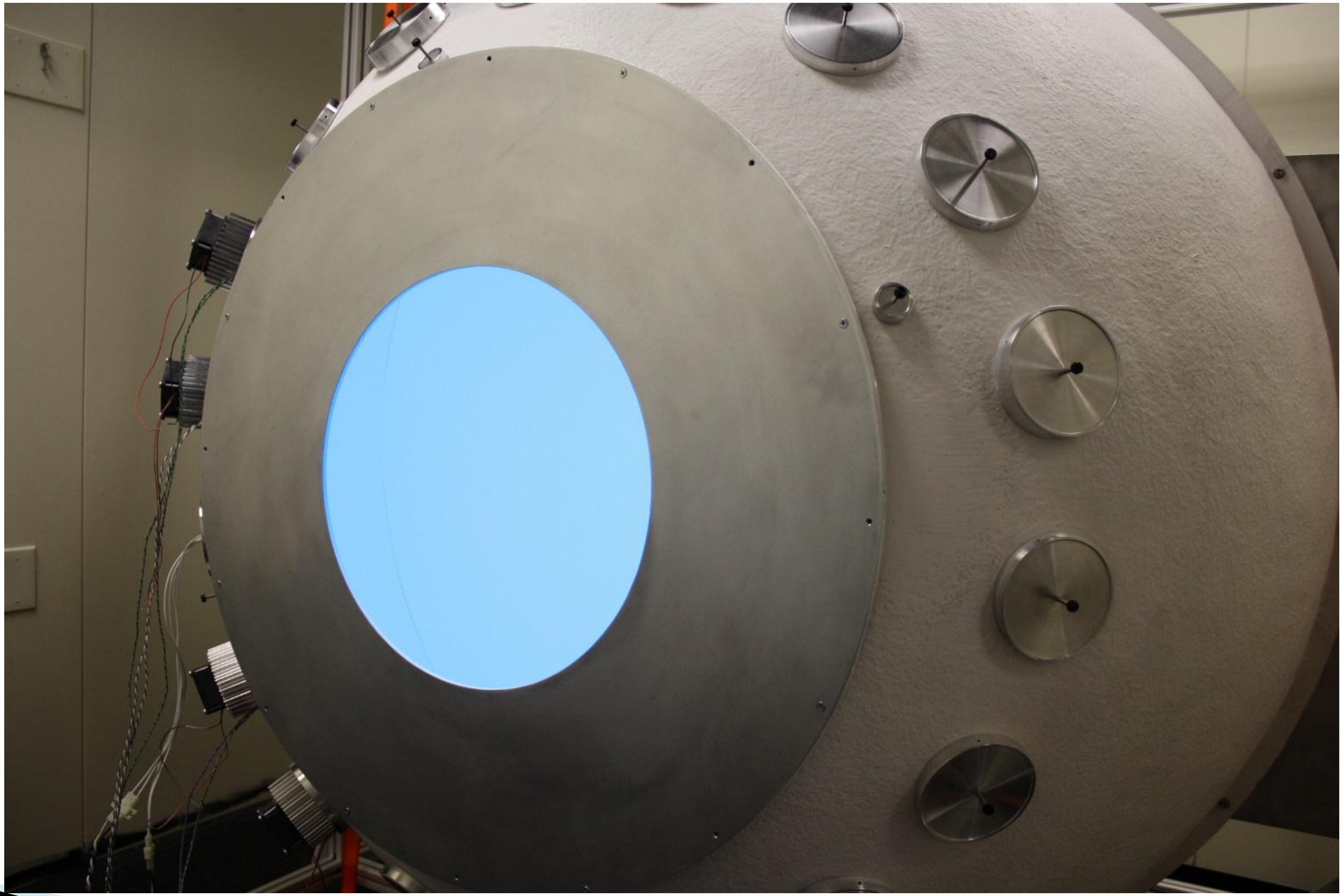
1500 mm Sphere Assembly



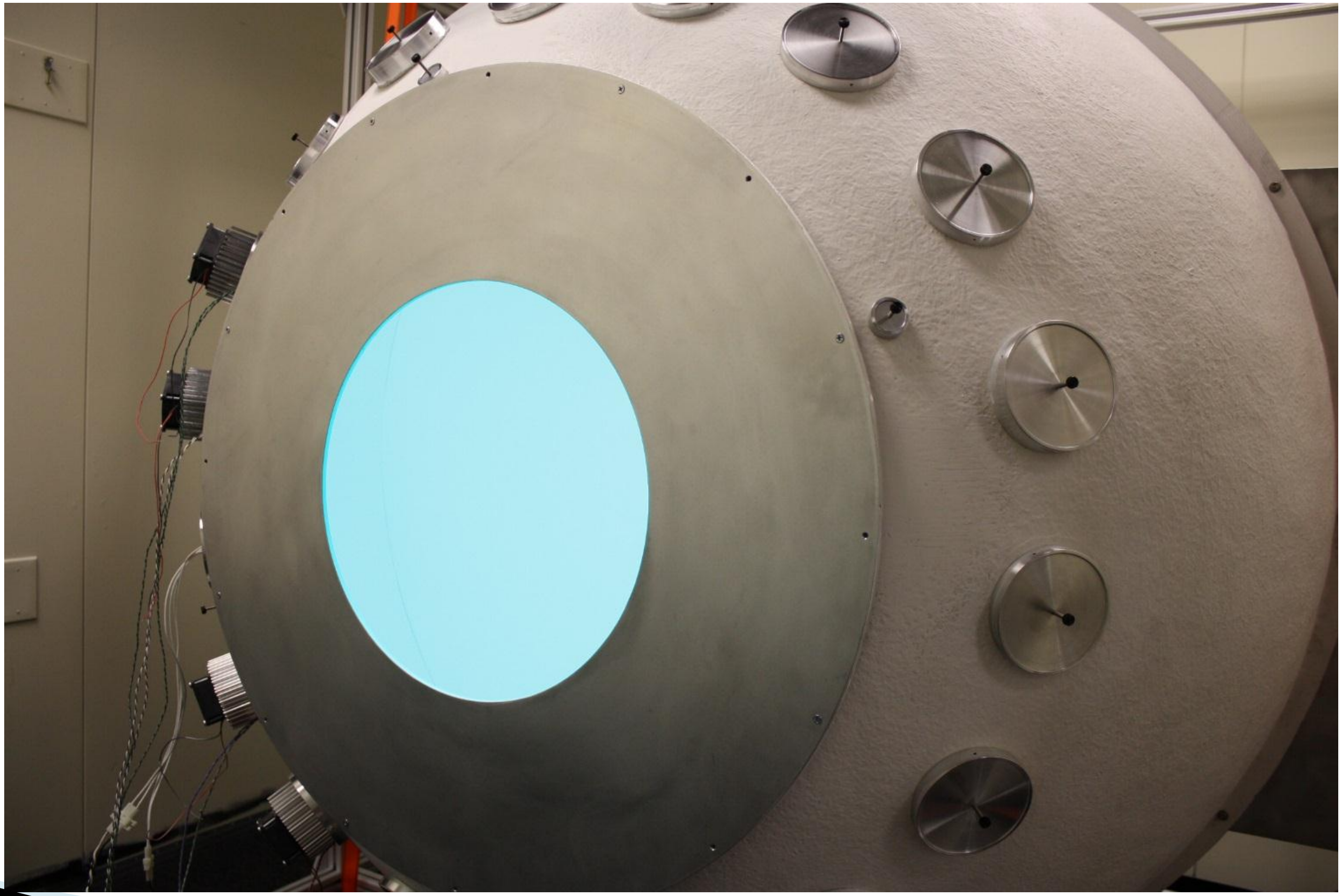
White Light LED



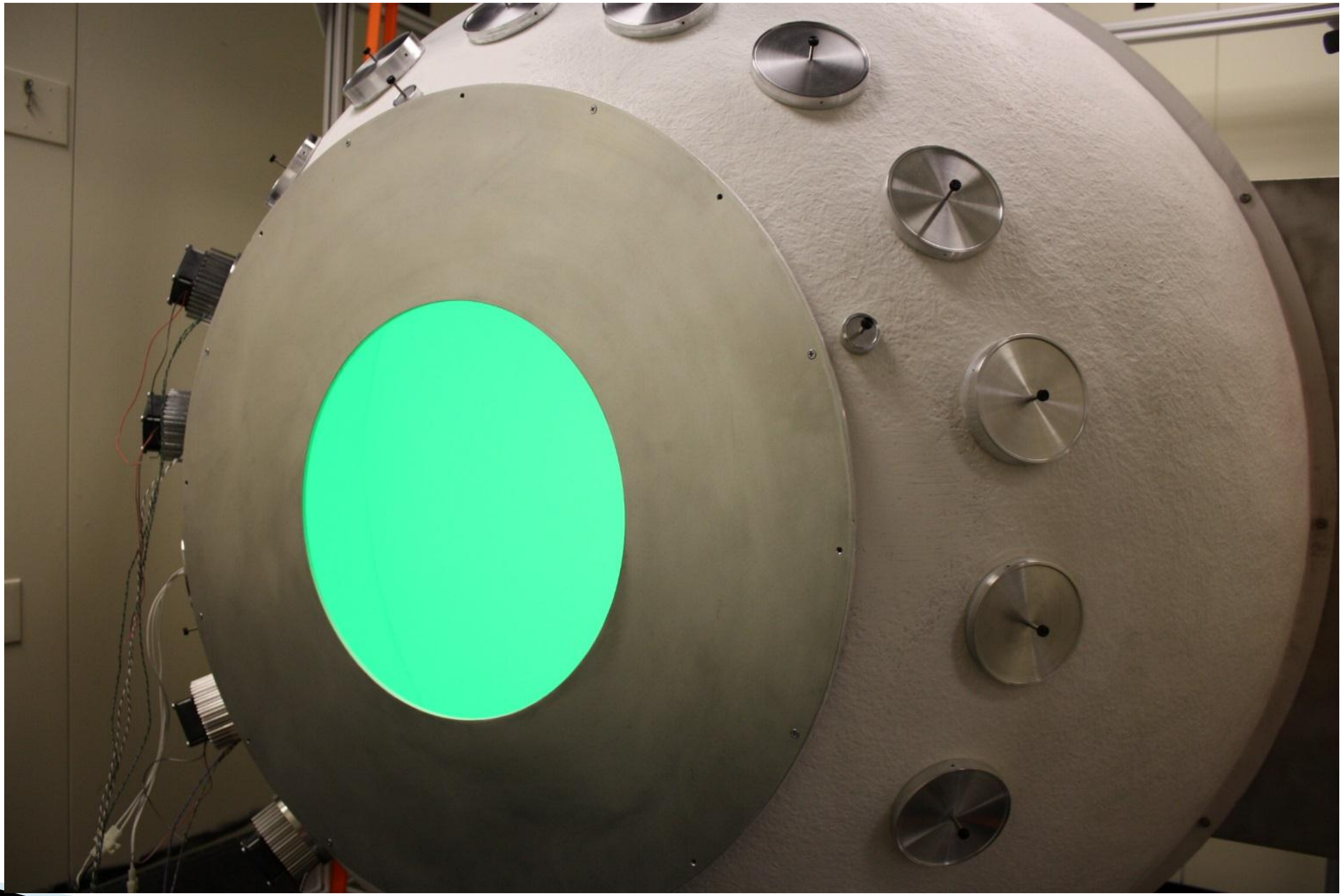
Blue Light LED



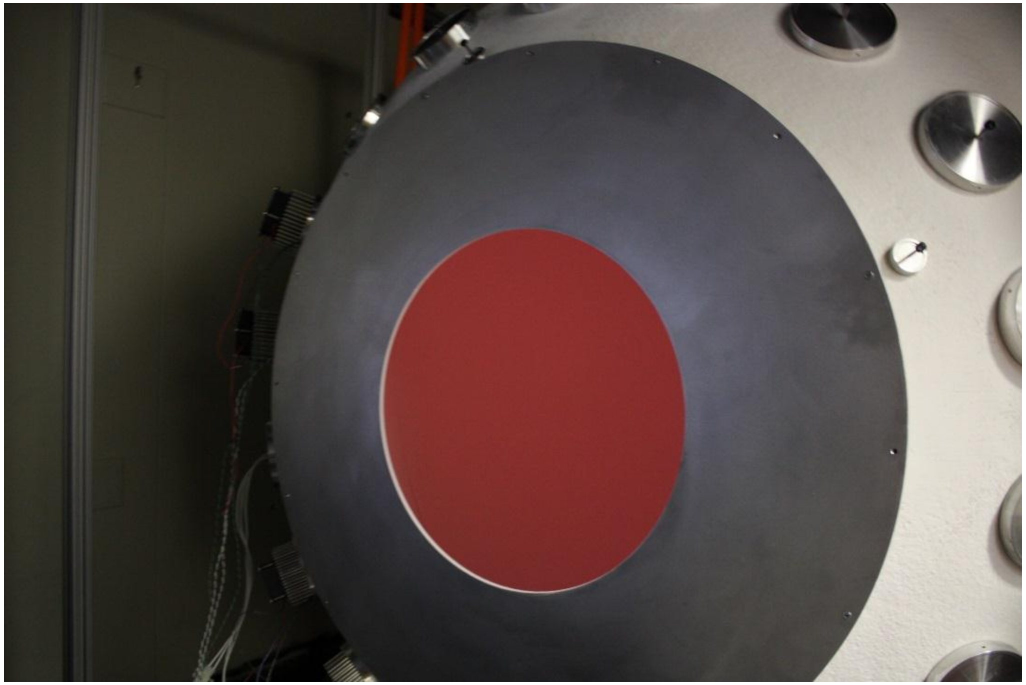
Cyan Light LED



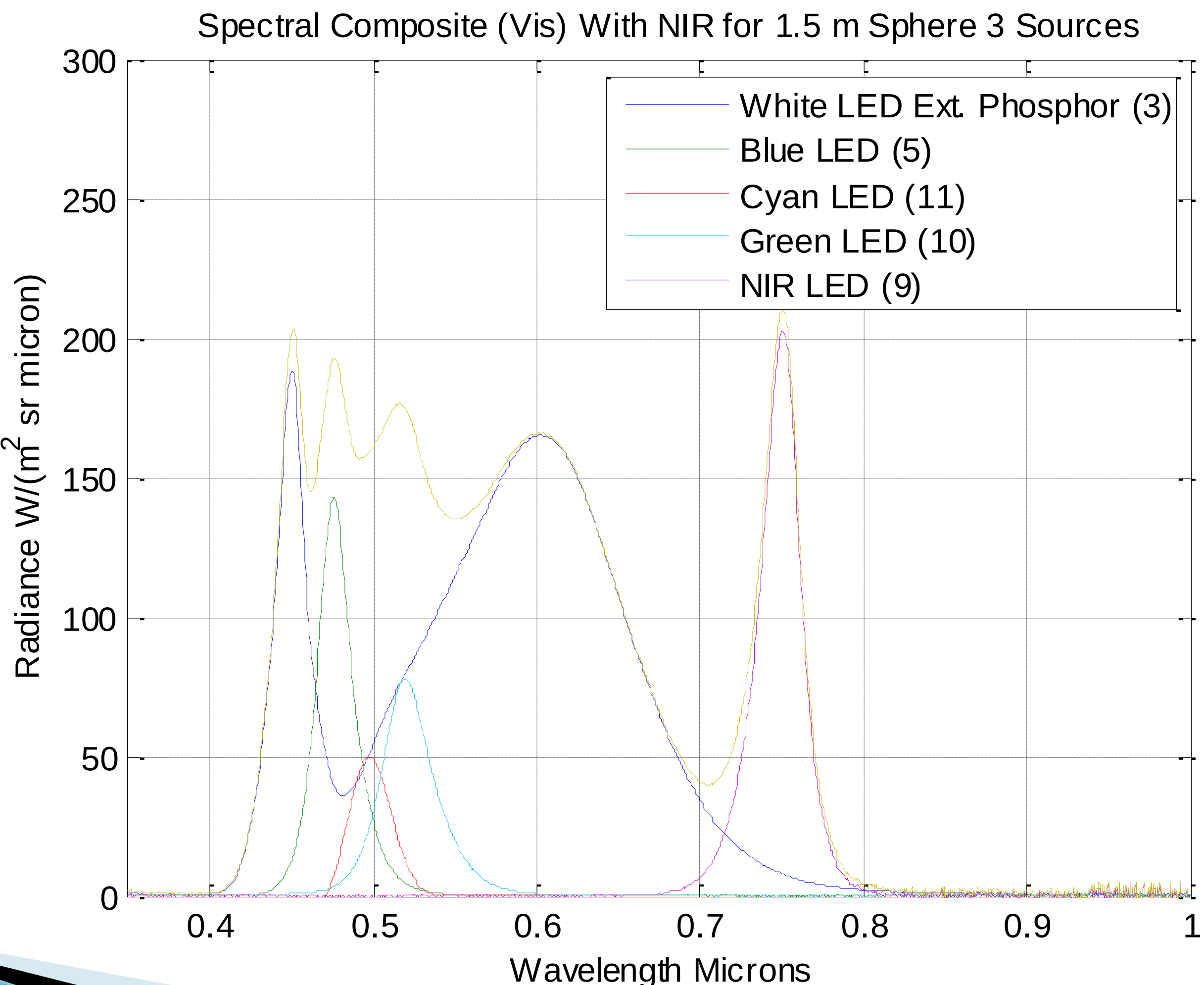
Green Light LED



Far Red 730 nm LED

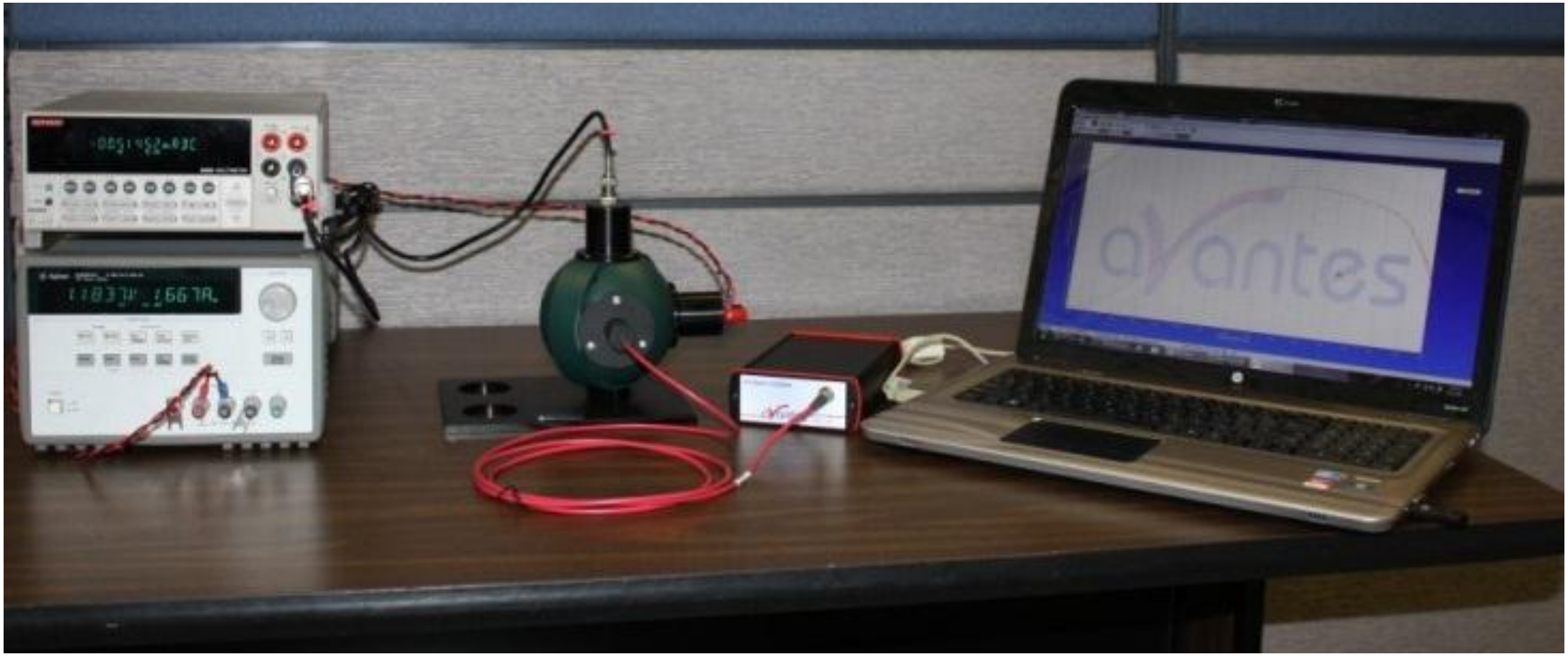


Spectral Synthesis LEDS Including NIR



Spectrometer Radiometric Calibration Maintenance

NIST Traceable Calibration
with an Integrating Sphere



Summary

- LEDs are enabling the development of integrating spheres
  - Spectral matching to solar spectra
  - Electronically variable controlled radiance
  - NIST traceable
  - Large spheres

Acknowledgements

- I2R received a cost matching grant from the NASA Office of Chief Technologist to further develop and commercialize integrating sphere technology developed at NASA
  - NASA previously funded the development of field portable integrating spheres for studying the stability of field spectroradiometers used in vicarious calibration of satellites